ACTIVE FORCE CONTROL ON ACTIVE SUSPENSION SYSTEM

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ABSTRACT

Active force control system is the most effective and robust system in surpass vibration on suspension system. The objective of this project is to study the performance of AFC on car suspension system. Three type of suspension were tested and compared which is passive suspension, active suspension with PID controller and active suspension with AFC system. The quarter car model is designed. Passive suspension is a suspension system that not equipped with any controller or actuator. For the active suspension, PID controller is used. This controller design deals with selection of proportional gain, derivative gain and integral gain. This parameters (Kp, Kd and Ki) is tuned by using try and error method. For the active suspension with AFC scheme, incorporated with PID controller, it also important to get the optimum value of estimated mass. From the result, active suspension with AFC scheme can reduce more vibration compared to active suspension with PID controller and passive suspension. In conclusion, the AFC system is the most robust and simple system in reducing the vibration on suspension system compared to active suspension with PID controller and passive suspension.

ABSTRAK

Sistem kawalan kuasa aktif adalah sistem yang paling berkesan dan teguh dalam mengatasi getaran pada sistem suspensi. Objektif projek ini adalah untuk mengkaji prestasi AFC pada sistem suspensi kereta. Tiga jenis suspensi telah diuji dan dibandingkan iaitu suspensi pasif, suspensi aktif dengan pengawal PID dan suspensi aktif dengan sistem AFC. Model suku kereta direka. Suspensi pasif adalah system suspensi yang tidak dilengkapi dengan mana-mana pengawal atau penggerak. Bagi suspensi aktif, pengawal PID digunakan. Sistem kawalan ini direka dengan kebolehan untuk menguruskan pemilihan berkadar keuntungan, keuntungan derivatif dan keuntungan penting. Parameter yang digunakan (Kp, Kd dan Ki) ditala dengan menggunakan kaedah cuba jaya. Bagi suspensi aktif dengan skema AFC, selain kawalan PID, ia juga penting untuk mendapatkan nilai berat anggaran. Hasil daripada simulasi, suspensi aktif dengan skema AFC adalah system yang boleh mengurangkan getaran lebih banyak berbanding suspensi aktif dengan kawalan PID dan suspensi pasif. Kesimpulannya, skema AFC adalah sistem yang paling berkesan dan mudah dalam mengurangkan getaran pada sistem suspensi berbanding suspensi aktif dengan kawalan PID dan suspensi pasif.

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LIST OF ABBREVIATIONS

AFC	Active Force Control
FSMC	Fuzzy sliding mode controller
Hz	Hertz
PID	Proportional-Integral-Derivative
PI	Proportional-Integral
PD	Proportional-Derivative

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Car suspension is used to make sure car's wheels are constantly contact to the road and given comfort to the driver and passengers. When a car passing through uneven road profile or hit the bump, it will cause vibration. This unwanted vibration and disturbance force could lead to damaging the structure, causing disturbing noise, fatigue and long term serious injury. This problem of unsmooth road profiles and its effect on vehicle unwanted vibration is due to kinematic excitations. Researchers study about this problem to develop the solution, whose objective is to minimize their effects on the driver and passengers.

Conventional suspension spring and damper characteristics is fixed and cannot be adjust according to specification needs. Standard suspension system only consists of sprung mass, unsprung mass, damper and spring. To minimize the effect of the road profile and maintain driver and passengers comfort follows the road profile circumstance, flexible suspension is being studied theoretically and experimentally by automotive manufacturers and academic research groups. This suspension must be flexible, so that it can be adjust depends on the road profile and desirable performance. Researchers also studied about the new applications of active and semi-active suspension system and special devices to solve this problem.

Semi active suspension is being developed. This suspension system can control the ride height according to the changes in weight and disturbance loading. It can react to internal loading without generating energy to the system. This suspension system also can stop the car from pitching while accelerating or braking.

Active suspension differs from the conventional passive and semi active suspension in which an actuator is attached in parallel with both the spring and the damper to generate energy into the system. The main advantage of employing an active suspension system is, this suspension offers adaptation potential, where the suspension characteristics can be adjust while driving to accommodate the road profile being through. Active suspension being popular topic and researchers comes with many different method and actuator. Yildrim has analysed the differences and made comparison between proportional-integral-derivative controller (PID), proportional–integral controller (PI), and proportional-derivative (PD) controller. While G. Priyandoko, M. Mailah, H. Jamaluddin study on vehicle active suspension system using skyhook adaptive neuro active force control.

Hewitt introduced the active force control concept in late 70s. They design the methodology for using active force control in their study and proposed the actuation concept, alternate control algorithm and also about an approach to solving the problem. In the design process section, they have explored actuators and their technologies, controller hardware and software, and sensors to be integrated effectively into the system. This method is recognized as a simplest, effective and easiest way to control dynamics system. Figure 1.1 shows the diagram of active suspension system including an actuator. The car body represented by the sprung mass, m_s. The tyre, wheels, brakes and part of the suspension is represented by the unsprung mass m_{us}. The suspension stiffness and damping are denoted by k_s and b_s respectively with the tire stiffness denoted by k_t. The road displacement, r, is prescribed by the road profile. Finally, the actuator force is denoted by f_s.

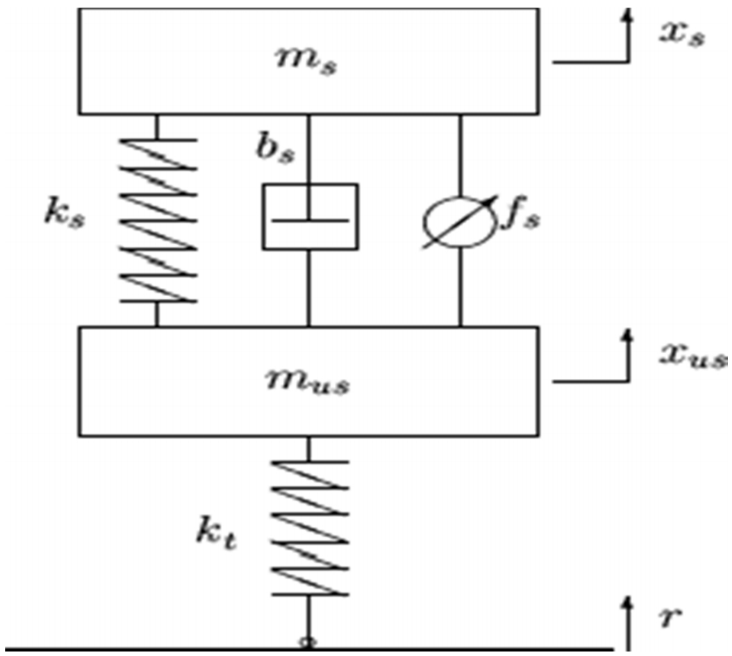

Figure 1.1 : Active Force Control

Where,

m_s = sprung mass

m_{us} = unsprung mass

k_s = spring stiffness

k_t = tyre stiffness

b_s = damping of the spring

f_s = actuator

x_s = sprung mass displacement

x_{us} = unsprung mass displacement

r = road profile

1.2 PROBLEM STATEMENT

Conventional suspension spring and damping characteristics is fixed and it is not adaptive to the varying disturbances which is cause by road profile that being traversed. So, active suspension system is introduced to offers adaptation potential, where the suspension characteristics can be adjusted while driving to accommodate the road profile. This active suspension can be achieved using a few approach such as PID controller, PI controller, PD controller, active force control (AFC) and many more. AFC is known as one of the robust active suspension.

1.3 OBJECTIVE

The objective of this project is to study and do analysing about AFC as force controller on active suspension system. This study will discuss about the effectiveness of using AFC in supressing vibration effect on passenger vehicles. The study will be carried out by using simulation in Matlab Simulink. The result will be analyse and some comparison between different type of suspension system which is passive suspension and proportional-integral-derivative (PID) force control will be made.

1.4 SCOPE

Below is project scope in order to achieve the objective:

1. Analyse and getting further understanding about AFC concept.
2. Study and compare the differences of using passive suspension, PID force control and AFC on suspension system.
3. Make a discussion and conclusion from the simulations in a final report.
4. The study will use the Matlab Simulink environment.
5. One degree of freedom motion are represented by quarter car model.
6. Quarter car model will be used as project model. Sprung mass represent the car body while unsprung mass represent part of suspension, wheel and brakes.
7. Disturbance frequency is 1.5 Hz.

1.5 THESIS ORGANIZATION

Thesis is starts with introduction in chapter 1. It discussed about the background and purpose of the project. Subchapter in chapter 1 is project background, problem statement, objective, and the scope of the project. This project will used simulation in Matlab Simulink environment.

Chapter 2 is literature review. Literature review described the current knowledge related to project about passive suspension system, semi-active suspension system, active suspension system, AFC, and actuator from other researchers.

Chapter 3 is the methodology of the project. It will discussed the plan or method used to do the project and a guidelines in solving the problem. The method used for this project is simulation in Matlab Simulink. Suspension, controller and actuator need to be design while control loop also needs to complete this project.

Next chapter is chapter 4 which is result and discussion. This chapter will show the result from the simulation proses and discuss about it.

Chapter 5 is conclusion and recommendation. It will discuss the conclusion of the project and recommendation for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 HISTORY

The purpose of suspension system on vehicles is to improve the ride comfort, road handling and stability of vehicles (Rao, 2010). By introducing of suspension system, acceleration amplitude of the sprung mass of a car may be restricted and tire deflection may be decreased, thereby enhancing effectively the above mentioned features. In 1901 Mors of Paris first fitted an automobile with shock absorbers. With the advantage of a dampened suspension system on his 'Mors Machine', Henri Fournier won the prestigious Paris-to-Berlin race on the 20th of June 1901. In 1920, Leyland used torsion bars in a suspension system. In 1922, independent front suspension was pioneered on the Lancia Lambdaand became more common in mass market cars from 1932. The important consideration is designing suspension is ride comfort, suspension deflection, and tire deflection. Conventional suspension only consist spring and damper without any controlling system.

The problem of this passive suspension is the characteristics of the spring and damper is fixed and cannot be adapt follows the road profile. Semi-active and active suspension is being studied and introduced to offer suspension with adaptive option. Semi-active suspension only capable of energy dissipation while active suspension can either store, dissipate or generate energy for the vehicle. This active suspension spring and damper characteristics can be adjusted while driving accommodates the road profile. It’s also more elastic and efficient than the other types of suspension, making it capable of providing better road-holding ability and ride comfort. Because of it, active suspension system control has attracted the attention of numerous researchers interested in improving the ride and the holding quality of a car.

2.2 QUARTER CAR MODEL

The vehicle model used for this project is quarter car model or one-fourth of the car body mass. This model consist of car body as a sprung mass, tire and brake components as unsprung mass, spring, damper and controller for active suspension system. The assumptions for this quarter car model is there is model is moving in one degree of freedom, tire as a linear spring without damping, spring and damper are moving in linear, wheels is always contact with the road surface, and effect of road friction to the tire is neglected. For this quarter-car model, vehicle roll and pitch motions are ignored and the only degrees of freedom included are the vertical motions of the sprung mass and the unsprung mass (Chantranuwathana, 2004).

2.3 PASSIVE SUSPENSION SYSTEM

Passive suspension is known as earliest and simplest design of suspension. It only consisted of sprung mass, unsprung mass, spring and damper without any force controller as in Figure 2.1. This type of suspension being called passive because it cannot add energy to the system (Rao, 2010). Spring is used to store the kinetic energy produce by the disturbance of the vehicle while damper is used to dissipate this energy. Passive suspension systems are subject to various tradeoffs when they are excited across a large frequency bandwidth. The system is an open loop control system and its designs to achieve certain condition only (Agharkakli, 2012).

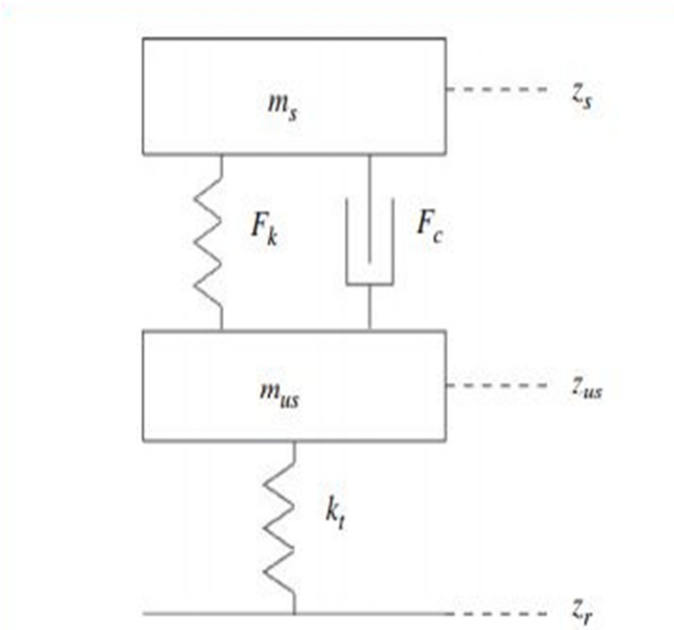

Figure 2.1: Passive suspension system

Source: Poussot-Vassal et al. (2008)

Where :

Fk = Spring stiffness

Fc = Damping constant

Kt = Tyre stiffness

Z_r = Road profile

Z_{us} = Displacement unsprung mass

Z_s = Displacement sprung mass

M_{us} = Unsprung mass

M_s = Sprung mass

Equation of motion for this passive suspension is :

Equation 1 : MsZs + Fk (Zs - Zus) + Fc (Zs - Zus) = 0 (2.1)

Equation 2 : MusZus - Fk (Zs - Zus) - Fc (Zs - Zus) + Kt (Zu – Zr) = 0 (2.2)

Passive suspension spring and damper characteristics is fixed and cannot be adjust according to specification needs.

2.4 SEMI-ACTIVE SUSPENSION

Semi-active suspension becomes popular research topic by automotive and academic researchers in order to improve the conventional suspension. This suspension offer improvement in ride quality by minimizing sprung mass acceleration and displacement. Semi-active suspension systems offer the adaptation of the damping or the stiffness of the spring to the actual desired response (Rao, 2010). It can control the vehicle height according to the changes in weight and disturbance loading. This system reacted to the internal loading without generating energy to the system. Typical bandwidth for semi-active suspension is 0-5 Hz.

Numerous type of semi-active suspension have been proposed and introduced such as using actuator magnetorheological (MR) fluid dampers, skyhook control, relative control and many more. Compare to active suspension, the disadvantage this type of suspension is it only can dissipate kinetic energy from disturbance without generate energy to the system. So it only effective on small frequency disturbance and low speed vibration.

2.5 ACTIVE SUSPENSION SYSTEM

Active suspension is a suspension with high bandwidth (0-50 Hz) which the springs and dampers of passive suspension are replaced by hydraulic struts controlled by a fast-acting closed loop control system. Theoretically, this suspension allows reduction in body vertical acceleration and can provide a driver and passengers less isolation from road unevenness while keeping admissible the road holding performances. The idea is that when the car meets a bump, the appropriate strut will retract the wheel. Conversely, when the car meets a hole, the strut will force the wheel downward. Both cases maintain the vehicle body at a constant ride height for driver and passengers comfort.

Various type of active suspension being study and develop by academic researchers and automotive engineers. Many technical papers were written about it or related subjects. However they are facing many problems from this development such as high cost of the system, high power consumption, low bandwidth, and limited usability. This suspension consists of various types of actuator such as PID controller, PI controller, AFC and many more.

Citroen Automotive were the first automotive group seriously introduced and applying active suspension on their automobile. This active suspension is developed based on a hydro pneumatic suspension. Lotus teams then developed this system and introduced it to their Formula 1 Grand Prix car between 1977 and 1982 (Ikenaga, 2000). They found it quite effective in improving their handling ability.

Fuzzy sliding mode controller (FSMC) is used to control an active suspension system and evaluated its control performance (Jeen Lin, 2009). FSMC will detect the error change to establish a sliding surface, and then introduced the sliding surface and the change of the sliding surface as input variables of a traditional fuzzy controller (TFC) in controlling the suspension system. He used quarter car model in Figure 2.2 as suspension model.

Figure 2.2: Quarter car model

Source: Jeen Lin (2009)

2.5.1 Active Suspension System with PID Controller

Proportional Integral Derivative (PID) controller is generic control loop feedback mechanism. This type of controller is widely used in industrial control system. This controller is function to correct the error between measured process variable and give a corrective action that can adjust the process (Salim et al, 2011). Example of usage PID controller is on active vehicle suspension. This system well known as excellently used for little disturbance and low speed vibration. However, PID controller performance is decreased when the system is operating at high speed and with presence of high disturbance (Mansor et al, 2010).

The process of selecting the controller parameters to achieved given performance specification is known as controller tuning (Mouleeswaran, 2012). The parameters need to be tuned is Kp, Ki and Kd. This controller needs to be tuning until we get the desired responses. In many case, series of fine tunings are needs until an acceptable results is obtained. Figure 2.3 shows the PID controller plant.

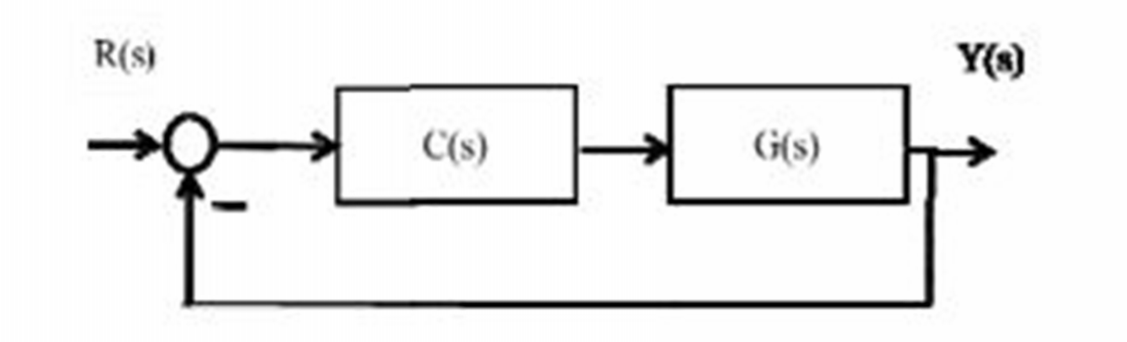

Figure 2.3: PID controller plant

Source: Salim et al (2011)

The PID system is designed prior to the implementation of AFC. The transfer function of a PID controller is given below :

$$G(s) = K_P(1 + \frac{1}{K_I s} + K_D s) \tag{2.3}$$

Where:

Kp = Proportional gain

Ki = Integral gain

Kd = Derivative gain.

2.5.2 Active Suspension System with Active Force Control

Works on Active Force Control (AFC) have been started by Hewit and co-workers in the early eighties which demonstrate that the dynamic systems under study can be made robust and stable in the presence of disturbances, uncertainties and/or parametric changes, provided that a number of simple criteria are fulfilled (Priyadonko, 2008). They design the methodology for using active force control in their study and proposed the actuation concept, alternate control algorithm and also about an approach to solving the problem. AFC can be shown in simple Newton's second law of motion:

$$F + Q = ma \tag{2.4}$$

Where F represented the applied force, Q is the disturbance, m is a mass of spring mass and a is the value of the spring mass acceleration. In the design process section, they have explored actuators and their technologies, controller hardware and software, and sensors to be integrated effectively into the system. This AFC is well known as a simplest, robust and most effective controlling system compared to others. Figure 2.4 shows the model of AFC system. The r, K_t, K_s, b_s, f_s, X_s, X_{us}, m_s and m_{us} represented road profile, tire stiffness, spring stiffness, spring damping, actuator force, sprung mass displacement, unsprung mass displacement, sprung mass and unsprung mass respectively.

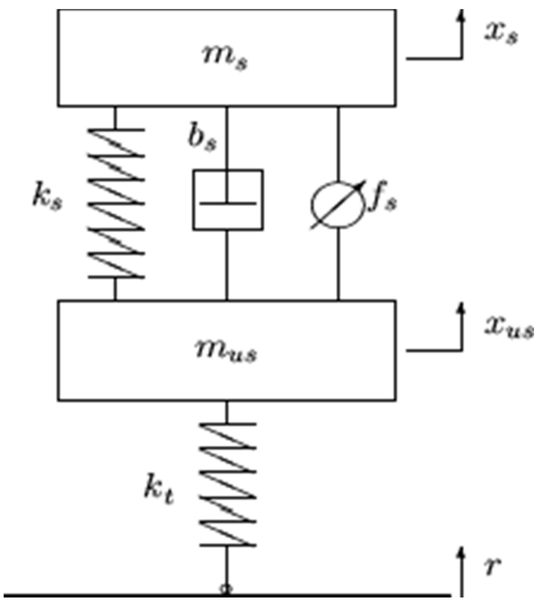

Figure 2.4: Active force control

Priyadonko in his study shows that the amplitudes of the sprung mass acceleration, and displacement for an active suspension based on skyhook adaptive neuro active force control (SANAFC) have a better performance compared to both the PID controller and the passive suspension system (Priyadonko, 2008). The AFC scheme for active suspension used by Priyadonko is in Figure 2.5. From his study, the inverse dynamics of the actuator are determined using neural network (NN).

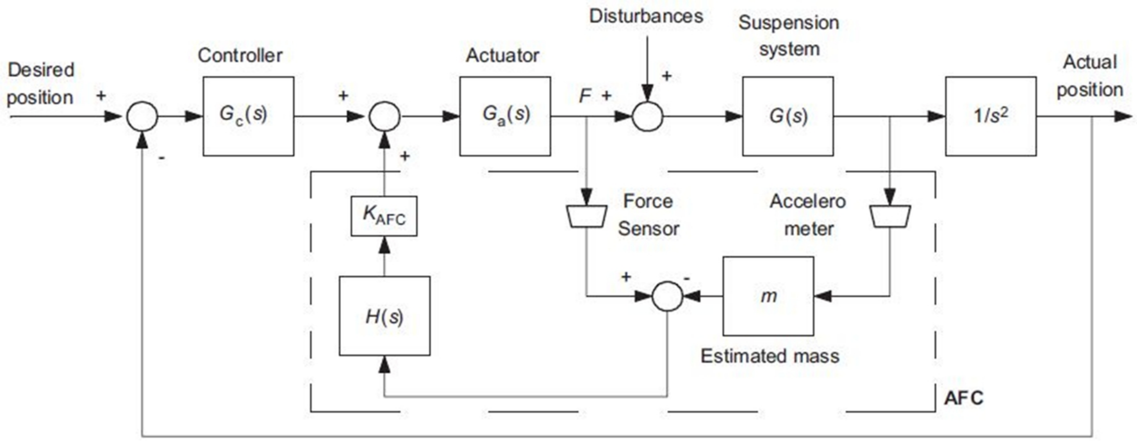

Figure 2.5 : AFC scheme for active suspension

Source : Priyadonko (2008)

2.6 MAGNETIC ACTUATOR

Magnetic actuator is an actuator which can deliver high-output forces, be driven at high frequencies and used very broad in various fields. In automotive, it used as force controller for active suspension. Magnetic actuator being developed to maximize suspension efficiency and increase its bandwidth. Magnetic actuators can be rotary or linear, and can have continuous or limited motion. The basic classes being are moving-coil, moving-iron and moving-magnet. Within these, the air gap length may either remain constant or vary with displacement, and while the majority of such actuators have only one degree-of-freedom, systems are emerging which are capable of providing multiple degrees-of-freedom of controlled motion. This actuator